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ORGANIZED PROGRAMS TO UTILIZE NATURAL ENEMIES OF PESTS IN

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MEXICO
UNITED STATES

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Programs In Mexico

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The urgent need of farmers of reducing crop losses in cultivated areas and that of entomologists to select more control measures adequate to each problem that might lead us to a good Pest Management Program makes it necessary to pay all our attention to what we have been and are doing as far as Economic Entomology is concerned, since we know that insect pests are showing a high selectivity to certain crops. Along with the tolerance and resistance to chemicals used for its control, the problem in our days is very dramatic for production costs in food crops have jumped due to the investment needed for pest control.

With this point in mind, most world countries are working intensively—and for some time now—into the possibility of utilizing more broadly natural enemies of plant pests from any biological origin (parasites, predators, virus, bacteria and fungi), the systematic and scientific utilization of this biological means existing in nature for controlling other living beings is a technology highly specialized within applied entomology. So we must gather scientific groups devoted full time to search to the last the big potential weapons created for mankind in this biological battle so he can fight back, reducing the damage and losses that pests cause every year on crops and animals which are his food source. Of course, this searching must start looking for a deep knowledge of the pest to be controlled and of the natural enemies that should be used.

For that, we must evaluate what action native beneficial fauna is doing and later, if no adequate control is present, take protective and balancing population measures through the possibility of introducing colonizing populations from other parts of the area, country, or the world, starting a real colonizing program—moving high numbers of pest enemies as quickly as possible, with a thorough inspection to avoid hyperparasites that might limit or even nullify the stabilization of these colonizing groups.

We also must consider massive rearing under control and conditions since we know that the limiting factor for a sound, biological control of plant pests depends on the availability of high populations of natural enemies for a precise time release.

It has been stated that the use of natural pest enemies is the cornerstone for pyramid of integrated insect control, otherwise we *cannot* even dream about control method integration, because by destroying the beneficial fauna—both native and induced—using other control measures would end in a one-way control, using only insecticides.

DISCUSSION

1. Since we must produce more food at lower cost, and that food must be of good quality and free from pests and diseases, it is very advisable to use as much as we can all the control measures that are available in nature that man itself has destroyed or reduced by his lack of coordination between his activities and nature stability.

2. The conservation and protection of ecological systems is something we cannot delay. Particularly, we who are in agricultural entomology that in our own countries are responsible for plant pest control to minimize pest damage to our crops and to keep those crops healthy and acceptable for our growing populations.

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Programs In Canada

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Biological control in Canada started in 1882 but in general these were casual approaches based on associations with U.S. entomologists (Beirne and Kelleher, 1973). It was not till 1910 that serious introductions were made against the larch sawfly by C. G. Hewitt. This was followed by projects on the browntail moth, the oystershell scale and the wooly apple aphid which were acclaimed as successes and led to the appointment of full-time biological control workers and the establishment of a Parasite Laboratory at Belleville, Ontario, in 1929 (Beirne, 1973).

As in the beginning there was close collaboration with U.S. counterparts, and facilities at Melrose Highlands were made available to Canadian biological control workers. Projects often parallel those in the United States and were to a large extent an extension of these programs into Canada. Biological control work was organized as a separate entity from other entomological research. And this separation was to continue in Canada until 1955.

The early success against the European spruce sawfly in the 1930's, by the fortuitous introduction of a virus, led to an emphasis on forest insects and the establishment of an Insect Pathology Laboratory at Sault Ste. Marie, Ontario. In 1954 an agreement was made which left responsibility for the biological control of forest insects with the Forest Biology Unit, which later moved from Agriculture Canada to another Department. But the Belleville Laboratory retained responsibility for importations of foreign collections for both forestry and agricultural establishments throughout Canada.

Although the Commonwealth Institute of Biological Control had established a laboratory near Zurich shortly after World War II to which Canada provided research grants, much of the work was still done by Canadian scientists, some of whom were on postgraduate studies in Europe. This policy was later abandoned in favor of one in which the C.I.B.C. was made the official agent for the collection of insects and information relating to biological control from other countries for Canada.

About 1955, changes in administrative structure similar to those made recently in the USDA, gave regional establishments autonomy in all research activities including biological control. In many instances this created a vacuum—these establishments had been accustomed to having Belleville initiate any biological control introductions considered necessary and many still hesitate to propose new work.

In 1972 the Belleville Research Institute was closed. The Importation Service was moved to Ottawa, the biocontrol of weeds to Regina, and a large segment of personnel sent to Winnipeg on a pest management scheme. Others were assigned to various regional stations. This had the effect of dispersing biological control to mission-oriented centers where the efforts are expected to be more fruitful.

Dr. Kelleher has provided a brief history of biological control in Canada up to 1972. An important event in that history was the decision to close the Belleville Research Institute, which was known for its involvement in biological control activities. The decision was necessary in order to bring the programs at Belleville in line with a "Management by Objectives" (MBO) edict being implemented in the Research Branch of Agriculture Canada. The Belleville scientists were sent to research establishments throughout Canada involved in mission-oriented research aimed at increasing agricultural production.

Two years have elapsed since the Belleville closure and absorption of its scientists into mission research of the Research Branch of Agriculture Canada is complete. It is too early to evaluate fully the successes and/or failures resulting from the move but it appears, if the attitude of most of the scientists involved can be used as a measure, all is going well.

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Biological control in Canadian agriculture, and I restrict my comments to that scene that is my realm of responsibility, is recognized simply as a component of the total system of crop protection, which is part of the crop production and utilization scene. It may be said that biological control is no longer treated in our Research Branch as a discipline of its own. Scientists in our organization who previously considered themselves as biological control specialists are now, with few exceptions, part of multidisciplinary research teams. They are working on self-defined protection projects aligned with their research establishment goals which in turn are harmonized with goals and objectives of the Research Branch.

Each project is aimed at a protection mission in agriculture and a time frame assigned to it which varies from 2 to 5 years. Each scientist is committed to a self-defined achievement within a self-specified period of time. The progress of each scientist toward his goal is assessed annually by himself, his peers, and his superiors through a system of checks and counter checks. His successes and/or failures are documented and are the criteria by which his program and himself are evaluated.

The Branch encourages its scientists working on protection aspects of crop production to develop the best methods possible to protect our crops. They are expected to learn through research as much as possible about the natural phenomena responsible for density changes which occur in insect pest populations while producers of food follow normal crop production practices. This knowledge will allow farmers to make sound decisions regarding strategies to be followed in order to control destructive pests.

The reassignment of scientists from Belleville with biological control expertise to multidisciplinary teams at mission-oriented research establishments in the Research Branch of Agriculture Canada is now fait accompli.

Alignment of their research programs and those already in place at these establishments since 1955 with the MBO program of the Research Branch is also completed. Time alone will tell us whether or not these management decisions were correct. Monitored progress so far reflects a trend towards success, but as I stated earlier it is as yet too early to tell.

The protection programs in the Research Branch of Agriculture Canada shown on the following pages have biological control research components associated with them.

Biological Control Programs In Agriculture Canada Research Stations

I Atlantic Provinces

St. John's West

European cranefly, ecology, control
Root maggots, *Hylemya* spp., ecology control
Sheep blowfly, control

Charlottetown

European corn borer, ecology, control
Tobacco cutworm, life history, control
Cruciferous insects, integrated control
European corn borer, ecology, control
Barley Yellow dwarf, vector control
Forage grasses, disease and insect control

Kentville

Atractotomus mali ("brown bug"), biology, control
Predators in apple orchards, management
Codling moth-leaf rollers, ecology
Winter moth, population dynamics
Apple maggot, control
Apple maggot, codling moth, selective pesticides
Tree fruit pests, integrated control
Apple orchard pest management
Cutworm investigations

Fredericton

Blueberry pest management
Aphid resistance in potatoes
Potato-infesting aphids, integrated control

II Quebec and Ontario

Ste Foy

European skipper, ecology, control

St. Jean

European corn borer, plant resistance
Olethreutids and Tortricids in orchards, integrated control
Mealy bugs, integrated control
Red mite, ecology
Apple maggot, ecology

Ottawa

Alfalfa weevil, population dynamics
Cereal leaf beetle, population dynamics
Greenhouse ornamentals pests, integrated control

Harrow

Vegetable insect control by viruses
Nitidulid beetles, biology, control
European corn borer, ecology
Greenhouse whitefly and spider mite, integrated control
Corn leaf aphid, ecology
Green peach aphid, ecology

Delhi

Dark-sided cutworm on tobacco, virus control

Vineland

Apple pests, integrated control
Oriental fruit moth, population dynamics
Application practices, evaluation
Vegetable insects, control

Smithfield

Hymenopterous parasitoids, artificial diets
Apple maggot, manipulation of spatial distribution

III Prairies (Manitoba, Saskatchewan and Alberta)

Winnipeg

Rapeseed pests, parasites
Rapeseed pests, behavior manipulations
Rapeseed pests and other, pathology
Red turnip beetle, biology
Rapeseed pests, integrated management

Regina

Biological control of selected weeds
Biological control of Canada thistle

Saskatoon

Lepidopterous pests on rape, biology
Flea beetles on rape, biology
Legume crop pests, biology, control
Insect population management in Prairie, systems
Mosquitoes, ecology, control

Lethbridge

Livestock resistance to ectoparasites
Common cattle grub, sterile male technique
Crop insects, sex attractants
Wheat stem sawfly, plant resistance, ecology
Cutworms, ecology, control
Potato insects, ecology, control

IV British Columbia

Vancouver

Aphids, control
European cranefly, biological control
Plant virus vectors, population dynamics
Tansy ragwort (weed), biological control

Summerland

- Stone fruit insects, integrated control
- Orchard mites, control
- Secondary and sporadic pests in orchards, integrated control
- Apples and pears, integrated control
- Codling moth, sterile male technique
- Pear insects, pest management

Programs In The United States

FEDERAL PROGRAMS

Importation of Natural Enemies

J. R. Coulson[1]

The U.S. Department of Agriculture is involved in many programs of several types utilizing natural enemies for control of pests. I will limit my discussion primarily to programs concerned with the *importation* of natural enemies of insect pests, although some of the importation activities are also directed against weed pests. Such importation programs are the responsibility of USDA's Agricultural Research Service (ARS).

Organizational Structure of ARS Biocontrol Programs

It may be helpful, first, to describe briefly the organizational structure of ARS biocontrol programs. ARS maintains two overseas stations for exploration, study, and collection of natural enemies of insect pests—one in France and one in Japan. There are also two overseas stations for the study of weed-feeding insects—one in Italy and one in Argentina. The four overseas laboratories are administered by ARS International Programs Division.

The primary ARS quarantine receiving center for natural enemies of insect pests is located at Newark, Del. Quarantine receiving centers for weed-feeding insects are located at Albany, Calif., and Gainesville, Fla.

In the case of natural enemies of insect pests, incoming material is either studied and released by personnel of the ARS laboratory in Delaware or more often, is shipped after quarantine clearance to other ARS or other Federal, State, or university laboratories that have an interest in receiving such material. Thus, much of the biocontrol material received from overseas by ARS leaves the hands of ARS biocontrol workers to be included in other ARS or non-ARS research and release programs.

An ARS Working Group on Natural Enemies of Insect, Weed and Other Pests was established in 1972 to aid in the coordination of the foreign, quarantine, and domestic study and release aspects of the importation program. This Working Group consists of ARS biocontrol specialists, members of ARS' International Programs Division and National Program Staff, and liaison representatives from USDA's Forest Service, Animal and Plant Health Inspection Service (APHIS), and Cooperative State Research Service, and from the Environmental Protection Agency.

[1] Beneficial Insect Introduction Laboratory, IIBIII, Agr. Res. Serv., USDA, Beltsville, Md. 20705.

Current Federal Biocontrol Programs

Only brief mention of some of the current ARS biocontrol efforts, primarily importation programs, can be made here. These include importations of biocontrol organisms against the gypsy moth, lygus bugs, greenbug, and alfalfa blotch leafminer. Incidental overseas studies are also being conducted on the Eurasian pine aphid for Hawaii, southern pine beetle for the University of Georgia, grasshoppers for ARS in Montana, and the pea weevil for the University of Idaho and ARS in Washington State.

Mass release and utilization programs are also being conducted by ARS and/or APHIS on the citrus blackfly in Mexico and Texas, pink bollworm in Florida, *Heliothis* in Texas, and the sugarcane borer in Florida and Louisiana.

ARS is continuing studies on the biocontrol of weeds. Some of the current target weeds include various species of thistles, knapweeds, nutsedges, spurges and tansy ragwort, and the aquatic weeds waterhyacinth, Eurasian watermilfoil, and alligatorweed.

Examples of Recent Importation Programs

I would now like to describe three examples of recent USDA biocontrol importation programs that will illustrate the involvement of ARS and of other Federal or State agencies.

Alfalfa weevil

ARS began a study of natural enemies of the alfalfa weevil in Europe shortly after 1952 when the weevil was discovered in the Eastern United States. Intensive domestic studies were also conducted by the ARS quarantine laboratory, then at Moorestown, N.J. The first releases of exotic parasites against the weevil were made in the Eastern United States in 1957. Over the next 12 years, 12 European parasite species were released, including *Bathyplectes curculionis*, which was established in the Western United States during earlier importations. By 1965, five species were established in the New Jersey-eastern Pennsylvania area and were dispersing throughout the Middle Atlantic States. A sixth species has since been established.

The five species quickly proved to be effective in reducing alfalfa weevil populations in New Jersey. A survey conducted by Rutgers University in 1970 showed a sharp drop in the use of insecticides to control the weevil by New Jersey farmers—96 percent of the farmers used insecticides in 1966, compared to only 8 percent in 1970. However, increases in weevil populations have recently been reported, and these are being closely monitored, as are the parasite populations, by ARS biocontrol workers.

In addition to release and establishment activities, ARS workers in New Jersey also undertook an extensive program for the dissemination of the established parasites to other areas where the weevil was spreading in the Eastern and Midwestern United States. As a result of this program and of natural dispersal, two or more of the weevil parasites originally established in New Jersey and Pennsylvania are now also established and dispersing in 22 States from Maine to South Carolina, west to Missouri, Michigan, and South Dakota, and in Ontario and Quebec. The New Jersey Department of Agriculture, the Virginia Polytechnic Institute, Michigan State University, and many other State agencies and universities played a large part in this dissemination program. The program has recently been most successful in Michigan, where one parasite of the adult weevil was reported to reach parasitism rates of 40 to 60 percent this year. The same parasite, *Microctonus aethiopoides*, reaches 80 to 90 percent parasitism rates in New Jersey.

Dr. William Day, leader of the ARS laboratory in Delaware, has recently calculated some of the benefits of the alfalfa weevil program in the States where the parasites are now established. Based only on per acre cost of application of insecticides no longer required in New Jersey and 12 other Eastern States, Dr. Day has estimated a

savings to farmers, in 1975 alone, of over $7 million. These annual savings are increasing as the parasites further disperse and populations increase; and the savings are, of course, cumulative. The total cost of the ARS program, now in its 17th year, is estimated to be about $1,000,000; this has been repaid about sevenfold by savings to farmers in 1975 alone.

Cereal leaf beetle

USDA's program to import cereal leaf beetle parasites represents a contrasting organizational approach from the alfalfa weevil program. In the alfalfa weevil program, ARS personnel conducted nearly all phases of the importation program—from foreign exploration and collection, to initial establishment, and to dissemination of populations of established parasites. In contrast, ARS involvement in the cereal leaf beetle program has been limited for the most part to foreign and quarantine activities only. This was partly because of the location of the pest problem in relation to the location of ARS biocontrol units, which precluded direct ARS involvement in release and establishment studies.

The cereal leaf beetle was first found in the United States in Michigan in 1962. The ARS overseas studies begun in 1963 resulted in the discovery of an egg parasite and four larval parasites of the beetle. Initial domestic studies and release activities were conducted under cooperative agreements with universities in Michigan and Indiana. In 1966, USDA's regulatory agency, now the Plant Protection and Quarantine Program (PPQ) (then the Plant Protection Division of ARS, until 1971) of the Animal and Plant Health Inspection Service (APHIS), established a Cereal Leaf Beetle Parasite Rearing Laboratory at Niles, Mich., to aid in the release, establishment, and dissemination of the exotic parasites. As a result of these release activities, at least four of the five cereal leaf beetle parasites were established in Michigan by 1972.

The beetle quickly spread from its initial establishment in Michigan and now occurs throughout almost the entire Northeastern United States and into Canada. As a result of work by the APHIS laboratory in Michigan, the parasites are also being rapidly dispersed. This is being done by a unique combination of the use of field insectaries and a laboratory culture of the egg parasite. The three larval parasites are presently being reared in field insectaries. After they are well established, they are collected for shipment and release elsewhere. Over 20 such field insectaries have been established in nine States, and five of these are currently producing larval parasites for release in new areas with the active assistance of county extension agents and other State and Federal personnel. In 1975, these larval parasites were released at 534 sites in nine States. By spring of 1975, the egg parasite had been released and established or dispersed throughout most of the present range of the cereal leaf beetle. It is now found in Canada and in a 10-State area from Michigan to New Jersey and south to Virginia. Two of the larval parasites are established in many areas in seven States, and the third is established at sites in four States.

In my opinion, if parasite activities such as are now conducted by APHIS in connection with the cereal leaf beetle had been possible in the case of the alfalfa weevil, alfalfa weevil parasites could have been dispersed with equal rapidity, making the benefits of that program much more quickly and widely felt. The dispersal of cereal leaf beetle parasites has been accomplished, currently by APHIS, with its regulatory responsibilities, about two or three times as fast as alfalfa weevil parasites have been dispersed by ARS, which is limited to such activities by its research responsibilities.

An evaluation of the effectiveness of the introduced cereal leaf beetle parasites is currently under study by Michigan State University and APHIS entomologists in Michigan and elsewhere. Information is still somewhat fragmentary and preliminary as to the real effects of the program. However, according to Dr. Thomas Burger, leader of the APHIS laboratory in Michigan, egg parasitism has reached highs of 87 percent at peak egg densities, and larval parasitism has reached 92 percent in some of the fields monitored. The effects of these high rates of parasitism on the host populations is not yet fully known.

Mexican bean beetle

A third example illustrates another type of program for the utilization of introduced natural enemies. This program is directed against the Mexican bean beetle on soybeans and involves ARS and several State agencies or universities.

In the 1950's, an ARS entomologist working in India discovered a larval parasite of a beetle related to the Mexican bean beetle. This eulophid parasite, *Pediobius foveolatus,* was imported in 1966 and was tested at the ARS quarantine laboratory in New Jersey to determine whether it could attack and develop on beneficial, entomophagous species of coccinellid beetles. When it was found to be specific to epilachnine, plant-feeding coccinellids, it was then field-released by ARS against the Mexican bean beetle in New Jersey and several other States. The parasite immediately demonstrated its potential effectiveness—over 80 percent of the bean beetle larvae at New Jersey release sites were parasitized by the end of the season. However, the parasite is unable to overwinter in the United States since it attacks the larval stage, and the Mexican bean beetle overwinters in the adult stage.

Therefore, studies were begun in 1972 on the potential utilization of this multivoltine parasite in a pest management program, in which the parasite would be cultured and reintroduced early in the season each year. These studies have been conducted over a wide area in southern Maryland and the Eastern Shore by the Department of Entomology of the University of Maryland with the aid of county extension agents in Maryland, Delaware, and Virginia under a cooperative agreement with ARS. The studies have been immensely successful. Rate of parasitism reached 80 to 90 percent by the end of the season, and the parasite demonstrated a remarkable dispersal capability, being found over 40 miles from any release site. The need for insecticides to control the Mexican bean beetle in some Maryland counties dropped sharply in 1974—in one county, only 13 percent of the soybean acreage was sprayed compared with 50 percent in the 2 previous years. According to Dr. Allen Steinhauer, leader of the Maryland program, preliminary data indicate that results in 1975 were even more spectacular.

Pediobius is now under study by entomologists in Florida, South Carolina, Virginia, New Jersey, Guam and Mexico. Dr. Reece Sailer, University of Florida, reports near eradication of the bean beetle in Alachua County, Fla., in 1975 and a spread of the parasite as far as Waycross and Tifton, Ga., distances of about 100 miles from release sites near Gainesville.

In view of the obvious potential of this approach to management of the Mexican bean beetle, several regulatory agencies have been approached regarding its utilization. The New Jersey Department of Agriculture now has cultures of *Pediobius* and plans to utilize the methods developed by Dr. Steinhauer to control the beetle in that State, and the Maryland Department of Agriculture has similar plans. Similar utilization in all areas where the Mexican bean beetle is a problem could be accomplished if APHIS initiated a program similar to that being conducted by their Cereal Leaf Beetle Laboratory in Michigan.

Organizational Difficulties Within Federal Biocontrol Programs

To recapitulate, the three examples I have discussed illustrate some organizational difficulties within the Federal biocontrol program. The alfalfa weevil program was run from the foreign exploration to establishment by ARS, but has since become bogged down in the routine, non-research function of dissemination of the established parasites. In the cereal leaf beetle program, on the other hand, ARS biocontrol workers would do little more than the foreign exploration and quarantine phases, simply because there were no ARS biocontrol personnel within working distance of the pest problem to conduct release and establishment work. APHIS is doing an admirable job of parasite dissemination, yet there is a research problem in the evaluation of the effectiveness of the parasites. With the Mexican bean beetle program, ARS conducted the foreign and initial domestic studies demonstrating the potential of the exotic parasite; other research units, the University of Maryland and others, are demonstrating the feasibility of the use of *Pediobius* in a pest management program; yet there is a possibility that these research results will never be put into practical application on a large scale.

In my view, the alfalfa weevil and Mexican bean beetle programs represent ideal situations—to a point. What is needed are more biocontrol *research* workers strategically placed to carry out such importation programs on *any* pest in the United States, from foreign exploration to the point of establishment, and/or the demonstration of the potential of the exotic parasite. Then, regulatory agencies such as APHIS, with ARS research workers serving in close consultation, should be available to assist in the application of the newly imported pest management tool, whether by extension of the established range of the natural enemy, as in the case of the cereal leaf beetle program, or in the large-scale practical application of such parasites as *Pediobius*. Research workers will also be required in the final phase of the program—the final evaluation of its effects.

In closing, I would like to add that the ARS Working Group has compiled a list of over 100 pest insects that could be likely candidates for biocontrol programs. It is hoped that when work is initiated on any of these, a mechanism will be developed to carry out the program to obtain the fullest potential from the introduced natural enemies. It should be remembered that the success of a biological control program often depends on the time, money, manpower, and especially the coordinated effort that is put into it.

Organizational Responsibility for Biocontrol Research and Development Inputs

R. I. Sailer[1]

While the previous speakers have emphasized organizational aspects of how biological control work has been and is being carried out, I intend to examine the question of how resources should be mobilized in order to obtain maximum benefits. No doubt members of this audience will hold other views as to the role of various governmental agencies as well as other institutions and private individuals in advancing the research and development phases of biocontrol. If so, I hope they will express views and indicate the alternative management mechanisms they would propose.

Scope of the Problem

In order to intelligently discuss management of biological control programs it is first necessary to comment on the definition and scope of biological control. In its broadest sense the term includes the biotic component of natural control of populations, manipulated use of natural enemies, the various autocidal methods including use of sterile insects, as well as plant resistance, and finally toxic substances produced by organisms. In its most restricted and traditional sense biological control is limited to manipulated use of natural enemies for control of insect pests and weeds. In common with the previous speakers my comments will concern biological control in its restricted and traditional sense.

Having restricted biological control to manipulated use of natural enemies we may next ask what "manipulated use" means. Stripped down to essentials manipulation falls naturally into three approaches—(1) Importation, (2) Conservation, and (3) Augmentation. Each of these three approaches involves different technology and a different mix of organizational inputs. In our complex society no single agency can be solely responsible for the research, development, and utilization functions of any of the three approaches. The agencies that we may expect to play some role in biological control are of two kinds, public and private, those of the public sector being Federal and State Government agencies while those of the private sector are private institutions, corporations, companies, partnerships, and individuals.

A fundamental difference between the two economic sectors is origin of their resources. Those of the public sector come from taxes while the private sector is supported by profits, and to an overwhelming degree this

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distinction determines the sector responsible for each functional component of the three approaches to biological control.

Importation: This approach involves importation of natural enemies, usually from foreign countries and usually against pests of foreign origin. It entails sequential activities beginning with selection of the target species, then exploration for natural enemies, screening candidates for introduction, collection, or rearing material, shipment, quarantine clearance, propagation, colonization, dispersal, and finally evaluation of results. Maximum efficiency and—more often than not—success depend on how well these activities are coordinated. Ideally, an importation project against a given target pest should be undertaken by a well integrated team that functions as a single administrative unit. The leader of the team should have full responsibility for directing and coordinating all phases of the project.

Selection of species to be targets of importation projects should be the responsibility of a national advisory body made up of representatives of Federal and State plant and animal protection agencies. At present there is an Agricultural Research Service (ARS) Working Group on Natural Enemies of Ins[illegible] Weed and other Pests. This Group includes liaison representatives from the USDA's Forest Service and from the Environmental Protection Agency (EPA). While well suited to select the targets and assign priorities for the ARS research effort in biological control, it is not adapted, and apparently not expected, to serve as an agency that would coordinate work at the project level. It is also doubtful that the Group will influence State activities to any considerable degree.

However they are established, priorities should be assigned after due consideration of economic factors including results of cost-benefit analyses. Equal weight should be given to feasibility as based on available guidelines and the best judgement of experienced biological control workers. Inevitably, priorities will be influenced by available resources. Estimated requirements of a high priority project may exceed the manpower and funds available for allocation. Such a project should be deferred until adequate resources are available.

Once targets have been selected and priorities established, importation programs become the responsibility of Federal and State research agencies. These consist of appropriate research units of the U.S. Department of Agriculture's Agricultural Research and Forest Services and State Experiment Station research units usually associated closely with Land Grant Universities. Normally an importation project will immediately or eventually involve work by several Federal and State research units. It may also involve one or more foreign research agencies.

Suitable candidates for introduction having been found by research, their actual importation will involve Federal and State regulatory agencies that have jurisdiction over issuance of permits allowing entry of insects and other organisms into the United States. Plans for importation of insects and other organisms to control weeds must also be reviewed and approved by an interagency "Working Group on Biological Control of Weeds" that includes representatives of research and regulatory agencies of the Departments of Agriculture and Interior and of EPA. While essentially an advisory group it attempts to anticipate and resolve conflict of interest questions that arise from different values placed on the injurious or useful characteristics of a plant. Recommendations of this work group guide decisions on issuance of entry permits by the Plant Protection and Quarantine Programs of the Animal and Plant Health Inspection Service (APHIS) of the USDA.

Once approved for entry, the foreign organisms must be received at a quarantine laboratory. Clearance through quarantine is generally handled as a research function. This is not illogical since the organisms have seldom been exhaustively studied and any information gained will be useful in subsequent propagation and colonization of a foreign species. The propagation and initial colonization of imported species should be a research function—up to the point where efficacy of the organism as a control agent has been demonstrated. At this point further work on the agent involves development and utilization functions, not properly considered research. While development normally contains a research component it also overlaps and interlocks with utilization.

Once an organism has been successfully colonized and found to be efficacious it should be dispersed as quickly as possible throughout the region where its host is an economically important pest. In the past, research scientists have assumed responsibility for most such dispersal activities. The work normally entails either laboratory culturing or field collection of stock for colonization. It is often costly in terms of both money and manpower and diverts these resources away from the primary mission of the research agency. Time spent in carrying out such work is disadvantageous to the research scientist whose career depends on research productivity. Yet the conscientious researcher too often has no alternative—either he did the best he could to insure that the results of his research were put to practical use or nothing was done. Therefore, biological control research agencies—both Federal and State—have usually carried out both development and utilization functions.

A good example is the program for biological control of the alfalfa weevil. With one exception this has been conducted by research scientists. The one exception involved the New Jersey State Department of Agriculture which recognized the importance of insuring that parasites were distributed throughout the State as quickly as possible and took appropriate action. As a result the weevil was quickly brought under control in New Jersey and that State became the beachhead from which the parasites have gradually dispersed to adjoining States. An ARS research effort greatly accelerated the dispersal of one important species *Bathyplectes curculionis* (Thompson) throughout the area of the Eastern United States infested by the weevil in the late 1950's. This parasite then paced the western spread of the weevil. Subsequently, State research personnel obtained stock of other species and as a result populations of other parasite species have been established in Virginia, Kentucky, Indiana, and Michigan.

Almost 20 years have passed since the alfalfa weevil parasites were first established in New Jersey. It has been 10 years since there was conclusive evidence that the parasites had effectively controlled the weevil in New Jersey. Yet to date there has been no mobilization of Federal and State plant protection agencies in a concerted effort to insure dispersal of the full complement of parasites to all alfalfa production areas. In the absence of such a program it may well be another 20 years before the full benefits of research on biological control of the alfalfa weevil will be realized.

A second example that may be examined with profit involves the cereal leaf beetle. In this case Federal and State plant protection agencies did mobilize almost as soon as the beetle was recognized to be an economically important threat to cereal production. However, insofar as work on natural enemies was concerned, there was failure to coordinate the research and development phases of the program. Resources for research and development were allocated simultaneously and as a result a facility originally intended to "massproduce" and disperse cereal leaf beetle parasites started operation before the responsible research agencies had found and completed preliminary evaluation of any parasites. As a consequence, the facility originally designed and staffed to fulfill a development and utilization function actually served as a much needed center for research—despite the fact that none of the scientists involved had titles of research entomologist. Nonetheless, by a happy if accidental concurrence of circumstances, the biological control of the cereal leaf beetle can now serve as a model of interagency cooperation involving Federal and State research and action programs. The cereal leaf beetle parasites are now being dispersed successfully in a manner calculated to affect control of the beetle in the minimum time possible and despite a 7-year-later start I am confident that the cereal leaf beetle will be effectively controlled throughout its range a good 10 years before the full effect of research on biological control of the alfalfa weevil is realized.

By way of concluding remarks under the *importation* approach, I would emphasize the need for improved coordination of effort among Federal and State agencies responsible for research and action programs. Only these agencies can effectively exploit the great number of natural enemies that should be imported and incorporated into our agro-ecosystems.

Conservation: This approach entails activities intended to protect natural enemy populations and to encourage their increase. It also happens to be a basic if not key objective of pest management. Insofar as organizational inputs are concerned, these will come from Federal and State research agencies responsible for developing management programs that most effectively restrain pest populations to noneconomic levels. Implementation of the results of this

research must be effected through Federal and State extension programs and through, as yet, an undeveloped segment of the private sector.

In order for the concept of pest management to be actually applied on a national scale, most growers will require expert guidance of a kind that will provide onsite surveillance of pest populations, and direct, or actually apply controls when these are needed. Therefore, I see need for a vast expansion of a new profession: that of the pest management consultant who will sell service rather than a commodity. Extension services must continue to play an important role, but I visualize this role as directed more toward the pest management consultant than to the grower.

If the objectives of pest management are to be achieved and full advantage taken of natural factors that limit and regulate pest populations, management decisions must be made on the basis of direct observation of pest populations in individual fields. Such observation must be made by trained personnel with a background of experience with local conditions. If this service is to be provided by agricultural extension workers it will mean a severalfold increase in the present work force. Obviously the growers themselves will ultimately determine how these services are provided. However, once growers are convinced of the need, it is my opinion that they will have greater confidence in services they have paid for.

Augmentation: This method of biological control involves production and release of parasitoids, predators, or pathogens for control of pests. The released organisms are normally already resident in the agro-ecosystem. The distinctive feature of the method, as opposed to conventional importation and colonization of new biological agents, is time and duration of effect. It is assumed that the effect of augmentation will be immediate protection of a crop; while the result of importation will be ultimate elimination of a pest problem.

The augmentation approach may take the form of either innoculative or inundative releases. In the case of innoculative releases, it is expected that control will result from action of a later generation of the released agent. When an inundative release is made, control should result from direct action of the released stock.

Among the methods of biological control, augmentation may well be the oldest. For centuries the Chinese have maintained colonies or purchased colonies of the predatory ant *Oecophylla smaragdina* (F.) and placed them in orange trees to reduce leaf-feeding insect populations (McCook 1882, Clausen 1956). In the early part of the last century, several European entomologists experimented with collection and release of parasitoids and predators of control of pests of which the gypsy moth was one (Sweetman, 1936).

In the United States, the method was first applied on a commercial scale against the citrus mealybug in California. Earlier, the lady beetle, *Cryptolaemus montronzieri* Malsant, had been introduced from Australia and found to be an efficient citrus mealybug predator. Unfortunately it could survive the winter only in the extreme southern coastal area of California. A mass culture technique was developed (Smith and Armitage 1931) making innoculative releases possible. Each spring the beetle would be colonized in mealybug infested groves and the pest would be quickly controlled. In the 1920's, 15 commercial insectories were producing the beetle and millions were released each year. However, in 1928, two mealybug parasites were found and successfully colonized. These proved so effective that periodic releases of *Cryptolaemus* were no longer needed (Compere and Smith, 1932).

In recent years there has been more or less continuous research on use of mass reared *Trichogramma* for control of various lepidopterous pests of crops. In the United States, a considerable effort was made to utilize *Trichogramma* during the 1920's (Flanders, 1930). Interest flagged as highly effective insecticides were discovered and came into general use. In the past 10 years interest has revived and research on use of *Trichogramma* is again being conducted at several ARS and State Experiment Station Laboratories. In other countries, notably the USSR (Telenga, 1958; Telenga *et al*, 1968; Dysart, 1973), The Peoples Republic of China (Anon, 1974; Collab. Res. Group, 1974), and Mexico (Memorias, etc. 1975), *Trichogramma* are being used routinely for control of crop pests over large acreages.

Other biological agents, notably *Chrysopa* against bollworms and *Spalangia* against houseflies, are also being studied by ARS and State Experiment Station scientists. Perhaps the most striking development relates to large field tests in Florida where the Cuban fly, *Lixophaga diatraeae*, has successfully controlled the sugarcane borer *Diatraeae saccharalis* (F.). As a result of a new production technique developed by the ARS Laboratory at Stoneville, Miss., control of the sugarcane borer through release of mass-reared Cuban flies appears to be both technologically and economically feasible (King, Martin, and Miles, in press).

The augmentation approach is currently being used in several European countries for control of mites and whiteflies in greenhouse cultures. The predacious mite *Phytoseiulus persimilis* A.-H. and the whitefly parasitoid *Encarsia formosa* Gahan are available from commercial suppliers for use by growers (Bravenboer, 1974). However, successful results depend in great part on the training and experience of the applicator. While examples of control through use of *Trichagramma*, *Chrysopa*, *Spalangia*, and the Cuban fly are primarily inundative, the use of *Phytoseiulus persimilis* and *Encarsia formosa* in greenhouses is innoculative.

Another example of the innoculative approach concerns use of *Pediobius foveolatus* Crawford against the Mexican bean beetle *Epilachna varivestis* Mulsant. Current work in Maryland and in Florida has shown that comparatively small numbers of *Pediobius* released at the right time and at strategic locations can virtually exterminate Mexican bean beetle populations over large areas. In Florida, release of 3,000 individuals in the Gainesville area and 4,000 at Quincy during the first half of May has produced incredible results. By the end of October, Mexican bean beetle larvae parasitized by *Pediobius* were collected in Georgia 370 miles north of Gainesville. During July and early August, the beetle disappeared completely from Alachua, Levi, Bradford, and Union counties of north central Florida. To date there is no evidence that *Pediobius foveolatus* populations can survive the winter season, and therefore the only practical method of utilizing this remarkably efficient parasite is through innoculative releases.

While results of research indicates that certain parasitoids and predators can be reared in sufficient numbers to warrant serious consideration of their use in innoculative or inundative releases against several serious pests, practical use of such agents in the United States is still extremely limited. Insect pathogens, on the other hand, present a very different picture. Here we find widespread use of *Bacillus thuringunsis* Berliner utilizing formulations produced and marketed by at least three companies. BT formulations are effective against a fairly wide spectrum of vegetable and other crop pests and can be directly substituted in many situations for a chemical insecticide. For these reasons, demand has been sufficient to interest private industry in production and sale of this biological agent. Industry is also supporting much of the research now being devoted to improving BT formulations.

Several viruses have been shown experimentally to be effective agents for control of such notorious pests as the bollworm, *Heliothis zea* (Boddie), the cabbage looper, *Trichophisia ni* (Hubner), and the codling moth, *Laspeyresia pomonella* (L.). Numerous problems have delayed commercial use of these viruses. First they must be produced in living insects or conceivably in cultured insect tissue. High production costs and restricted market prospects due to their high degree of host specificity reduces incentive to develop these microbial insecticides. Finally, because of their viral character and possible, though improbable, pathogenicity to other animals, the need for exhaustive tests and development of test protocols has slowed Federal registration for commercial use.

From the above comments on the augmentive approach to use of natural enemies, it is evident that organizational inputs needed to exploit this method run a gamut of public and private agencies. It is also evident that successful, large-scale use of the augmentative approach will require inputs far beyond those now available from both the public and private sectors. This is particularly true of uses involving parasitoids and predators. With a few possible exceptions there is little prospect that potentially useful species can be produced commercially and sold for direct use by growers. It is not that growers lack the ability to use such agents. Certainly any successful large-scale farmer could master the application techniques, but it is unlikely that he will find time in his busy schedule to monitor his pest populations closely enough to correctly time applications. Also assuming that production problems are solved, there remains the problem of delivery from the production unit to the field. Parasitoids and predators have short

"shelf life" and will require a tightly organized delivery system. There will be no buildup of inventories to meet anticipated pest outbreaks. Production facilities will have to be maintained and with minimum lead time, ready to scale up production to meet anticipated needs that may not materialize. I can't see private capital being ventured in such enterprises. If it is in the public interest for parasitoids or predators to be used in augmentation programs then the cost of standby facilities should be borne by public agencies.

Further Discussion and Conclusions

At the present rate of successful beneficial insect importation, it will be another 200 years before all foreign species useful to American agriculture can be added to our agro-ecosystems. The conservation approach to use of natural enemies requires vastly more information concerning pest management systems than is now available. It also requires the services of a new kind of professional-pest managers and use of these services by growers. With the exception of pathogens, the augmentation approach has barely moved beyond the experimental stage—at least in the United States. It seems abundantly clear that greater resources must be available before biological control methods can be fully exploited. This is scarcely a new or original conclusion but is, nonetheless, as inescapable as death and taxes if biological control is to assume a more important role in management of pests.

Biological control workers all too often read or hear depreciating comparisons of biological control with chemical control. Their hackles generally rise with good reason. First off, the immediate objectives of the two control systems are different. Chemical control is well suited to protect standing crops; by and large biological control is not. But how many pest problems have been eliminated by chemical control? I can think of only three—Mediterranean fruit fly in Florida, Kaphra beetle, and the cattle tick. At the same time a dozen pest problems could be listed as created by controls applied against other pests. By comparison, biological control working with vastly inferior resources has reduced a very considerable number of important pests to, or near, noneconomic status.

Having mentioned comparative availability of resources—the October issue of Agri-News carries an interesting item. It reports that in 1973, the last year for which data are accessible, the chemical industry spent $110 million on Research and Development of pesticides. It adds that R&D costs for each new marketed product amounted to $6 million. In 1972 I attempted to estimate the total costs of R&D relating to use of natural enemies. This included all Federal, State, and Territory work done since 1888. I could account for no more than $20 million as actually spent on work directly concerned with research on finding and exploiting natural enemies of insect pests and weeds.

Reasons for the disproportionate support of chemical and biological control are obvious. Money spent for pesticide research generates profit to the manufacturer and money spent for purchase and application of pesticides normally results in increased production and profit to the grower. In the case of biological control, money for research comes from taxes and growers are less interested in long-term benefits to be expected from biological research. The high risk resulting from lack of knowledge together with problems of production and delivery as well as uncertainty concerning continued demand virtually precludes private industry from any important role in production and use of parasitoids and predators. If these agents are to be used, R&D costs must be borne by public agencies. Pathogens offer a somewhat more attractive field for private industry. But for better or worse, it appears that public agencies must play the lead role in developing and to a great extent in the actual application of biological controls involving parasitoids or predators.

However, additional resources alone will not insure fully effective utilization of parasitoids and predators. It will be equally as important to insure that these resources are utilized efficiently by agencies best adapted to carry out research, development, and utilization functions. Finally, it is essential that the activities of these agencies be integrated into systems that are sufficiently versatile to meet the requirements of the different methods of biological control and at the same time accommodate the different procedures needed to exploit individual natural enemy species. This latter consideration is of special importance since each species will exhibit different requirements and capabilities.

Recognizing that no system of organization can be fully suited to meet all anticipated and unanticipated needs, it is scarcely possible to do more than indicate the type of agency best able to carry out the work involved in each of the three approaches to biological control.

Organization Inputs to Importation of Natural Enemies

Selection of targets: A national working group on biological control of insect pests and weeds.

Taxonomic inputs: The USDA, ARS, Systematic Entomology Laboratory, Smithsonian Institution, public and private universities and foreign institutions.

Foreign exploration and research: ARS, State Universities and Experiment Stations, and foreign institutions.

Quarantine clearance: ARA, State Universities and Experiment Stations, APHIS, and State plant protection agencies.

Propagation for preliminary evaluation: Federal and State Universities and Experiment Stations.

Approval for release (primarily weed feeding species): Intergovernmental "Working Group on Biological Control of Weeds." APHIS and State plant protection agencies.

Colonization and efficacy: Federal and State Universities and Experiment Stations.

Utilization through dispersal throughout infested area: APHIS and State plant protection agencies.

Evaluation of benefits: Federal and/or State research agencies in cooperation with Federal and/or State plant protection agencies.

Organizational Inputs to Conservation of Natural Enemies

Research designed to establish limiting factors: Federal and State research agencies.

Research designed to protect and increase natural enemies (a key element of pest management): Federal and State research agencies.

Utilization of research results: Cooperative Extension Services, pest management consultants, and growers.

Evaluation of benefits: Federal and State research and extension agencies and grower acceptance.

Organizational Inputs to Augmentation of Natural Enemy Action Through To Rearing and Release

(1) Parasites and predators.

Selection of potential agents for use in augmentation approach: Federal and State research agencies.

Establishing feasibility of control: Federal and/or State research agencies through pilot test stage.

Utilization: Production—by Federal and State plant protection agencies, grower cooperatives, and to a limited degree private business. Application—by same agencies and to a limited degree by growers.

Evaluation of benefits: Federal and State research agencies and grower acceptance.

(2) Pathogens.

Discovery of potentially useful pathogens: Industrial, Federal, and State research agencies.

Development research: By same agencies.

Utilization: Production by industry, marketed through commercial channels, and applied by commercial applicators and growers.

Mechanisms for Insuring Program Coordination

Program coordination is a highly critical element in both research and operational aspects of biological control, particularly that involving importation and augmentation activities. Use of living organisms for control of pests or as components of a pest management program will require a very different management structure than evolved for chemical control of pests. Success of importation projects is to a great extent dependent on how resources are allocated among the exploration, collection, quarantine, propagation colonization, dispersal, and evaluation phases of the work. To an even greater extent success depends on how well this sequence of essential steps is integrated into an efficiently functioning program.

While there is need for direct lines of administrative responsibility for direction and supervision of research through its sequential stages, coordination of effort among the numerous Federal and State research agencies is scarcely less important. There is an equally important need for coordination of effort among the various agencies that contribute to the dispersal of a biological agent to all geographic areas where it is needed. To produce best results at both the Federal and State levels each should have two interacting agencics:

1. A line agency with full program responsibility for allocating resources required to fund, import, and carry out research needed to demonstrate successful colonization and effectiveness of beneficial species.

2. A line agency with full program responsibility for allocating resources needed to distribute an effective beneficial species throughout the geographic area adversely affected by its host. This agency should also have responsibility to produce and carry out programmed releases of natural enemies for immediate pest control—where the method is deemed feasible as a result of prior research.

Finally, there is need for a third kind of organization perhaps best called *A Working Group.* The working group should be a plural concept and operate at two levels: (1) Selection and assignment of priority of pest problems and (2) coordination of work on individual pest problems.

The first type of working group would include representatives from each Federal Agency with program responsibilities for research or pest management activities involving biological control. Similar State agencies would be represented in the working group by a representative from Cooperative State Research Service. This should be a single body.

The second category of work group should consist of representatives of all Federal and State research agencies having responsibility for a biological control work on a specific pest or crop. There should be as many working

groups of this category as there are suitable problems. A representative of the responsible APHIS and/or State action agency should serve as an ex officio member of each of these Work Groups.

While during recent years interest in biological control has increased markedly and to some degree resources have also been augmented, organization has deteriorated. Regionalization of the ARS research programs has interposed administrative barriers between sequential stages of research involving importation of beneficial species. Regionalization has also complicated integration of concurrent research involving two or more ARS regions. If biological control is to function efficiently and effectively at the national level, means must be found to provide importation programs with line supervision encompassing all foreign and domestic phases of work. Until this happens, the most effective organizational inputs to introduction programs will be provided by State research agencies and individual USDA laboratories where such line responsibility can be exercised.

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STATE PROGRAMS

P. S. Messenger[1]

Introduction

In the United States, classical biological control programs at the State level are carried out mainly by either State Departments of Agriculture or State Agriculture Experiment Stations. The latter are most often associated with State universities, although not invariably. By classical biological control programs I mean, of course, the importation and use of exotic natural enemies to control insect and weed pests. This is not the only kind of biological control work done in the States for there are also programs aimed at the augmentation and/or conservation of natural enemies already present in the regions under consideration but which, unaided by man, are not sufficiently effective to reduce pest abundance to economically acceptable levels. Programs of this sort are less common than those of the classical type, though not necessarily less important. Not only have both State Departments of Agriculture and State Agricultural Experiment Stations supported natural enemy augmentation programs, but so also, in a few cases, have commercial biological control and pest management agencies.

Work on biological control at the State level was initiated at the turn of the present century with the encouragement and support of the Federal authorities. Subsequent to the successful cottony cushion scale control program in California in 1889, a program carried out by U.S. Department of Agriculture personnel and funds, work on biological control expanded, though with less dramatic results, in the years immediately following. Most such work continued to be due to Federal efforts until 1903 when in California a State funded and staffed biological control insectary was put into operation to participate jointly with the Federal activities (Doutt 1964). Similar work was initiated in Hawaii under what was then known as the Territorial Board of Forestry and Agriculture. Again, the early biological control work in Hawaii was a joint venture involving both U.S. Department of Agriculture scientists and Territorial Board staff.

Other early efforts by State or other non-Federal agencies included the participation by the State of Massachusetts personnel with U.S. Department of Agriculture staff in the gypsy moth project initiated in 1905. In 1907, University of Kansas scientists collected and redistributed the parasite *Aphidius* (Lysiphebus) *testaceipes* (Cresson) to improve the biological control of the greenbug *Schizaphis graminus* (Rondani) in the northern Great Plains region of Central United States.

The Spectrum of Biological Control Work

To review the present programs of biological control in the States, it is useful to categorize these efforts according to the following scheme:

A. *Complete programs* - These include: (1) target selection and evaluation, (2) foreign exploration and importation, (3) mass culture and colonization, (4) post-release evaluation, and (5) studies of natural enemy biologies and ecologies (van den Bosch and Messenger 1973).

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In those institutions that carry out complete programs, local staff usually have substantial experience with the insect pest complexes of those crops of major local importance. Thus they are able to evaluate the nature and appropriateness of both resident and new pest species with respect to possibilities for biological control, the presumptive origins of the pests which must be known before exploration for natural enemies can be undertaken, and the taxonomic categories of natural enemies that may be expected to be found in association with the target species. Expertise at both efficient quarantine processing and cultural requirements of a wide variety of natural enemies is also available in such programs. Colonization and frequent, periodic, post-colonization monitoring for natural enemy establishment and subsequent pest population suppression are other activities that are reinforced by this concentration of mutual effort by such local staffs.

B. *Partial programs* - These involve: (1) mass culture and/or colonization, (2) post-release evaluation, and (3) studies of natural enemy biologies and ecologies. Target selection and evaluation, and natural enemy cultures are provided by other agencies, most often U.S. Department of Agriculture scientists but also occasionally by State (for example, California) or foreign (for example, Canada Department of Agriculture or Canadian Forest Service) institutions. A few of these agencies (New Jersey State Department of Agriculture, Pennsylvania State Bureau of Forestry, Virginia Polytechnic Institute) use their own quarantine facilities for receipt of natural enemy shipments from overseas.

C. *Limited programs* - In these, only (1) post-release evaluation of colonized natural enemies, and/or (2) natural enemy biologies and ecologies are studied. Lack of special facilities and funds for their maintenance prevent any greater level of effort. As in the case of those partial programs described above, other phases of biological control work are provided by cooperators.

Because we are concerned mainly with organized programs of biological control leading eventually to actual attempts to control pests, I shall not consider the more restricted ecological studies of natural enemies and their impact on host or prey populations carried out by numerous entomologists, other than to note that this includes a great deal of valuable work on parasite or predator biologies, systematics, behavior and so on. What this means is that the number of scientists and institutions involved in programmatic aspects of biological control is not very great. In fact, as is illustrated in the next section, agencies at the State level that carry on complete programs of biological control are notably few in number.

State Level Agencies Doing Biological Control Work

The agencies carrying on organized programs of biological control are:

Complete Programs:

California - University of California, Division of Biological Control, Berkeley

University of California, Division of Biological Control, Riverside

Florida - State Department of Plant Industry; and University of Florida, Gainesville, Department of Entomology and Nematology

Hawaii - State Department of Forestry and Agriculture; and University of Hawaii, Department of Entomology

Partial Programs (A):
(those with quarantine facility)

Pennsylvania - State Department of Environmental Resources, Bureau of Forestry, Middletown

Virginia - Virginia Polytechnic Institute (State Agricultural Experiment Station), Department of Entomology

Partial Programs (B):
(those that mass-culture, colonize and evaluate, only)

Connecticut - State Agricultural Experiment Station, Department of Entomology, New Haven

Indiana - Purdue University (State Agricultural Experiment Station), Department of Entomology, West Lafayette

Michigan - Michigan State University (State Agricultural Experiment Station), Department of Entomology, East Lansing

New Jersey - State Department of Agriculture, Trenton

New York - Cornell University (State Agricultural Experiment Station), Department of Entomology, Ithaca

Oklahoma - Oklahoma State University (State Agricultural Experiment Station), Department of Entomology, Stillwater

Oregon - Oregon State University (State Agricultural Experiment Station), Department of Entomology, Corvallis

Pennsylvania - Pennsylvania State University (State Agricultural Experiment Station), Department of Entomology

Washington - Washington State University (State Agricultural Experiment Station), Department of Entomology, Pullman

This list of agencies supporting partial programs (B) of biological control is very likely incomplete. It includes those whose staff scientists have reported or published the existence of such activities in recent years.

Virtues of Complete Program Capabilities

The records of accomplishments in biological control support the contention that those agencies capable of conducting complete, locally organized, "vertically integrated" programs of biological control are much more likely to attain satisfactory pest suppression results. The reasons for this include (a) better planning and implementation of foreign exploration and importation of new natural enemy species, (b) better evaluation and transfer of biological information progressively along the functional chain of activities (target pest selection and evaluation, exploration, importation, quarantine processing, mass culture, colonization, evaluation of results), and (c) greater concentration of technical competence and facilities for carrying out the functional chain of activities.

To illustrate, of the total of 38 cases of completely or substantially successful biological control (sensu DeBach 1964, 1971) in the continental United States, 32 of these occurred in California and Hawaii. Some of these, of course, are to be credited fully or jointly to USDA personnel and facilities. But the majority of such cases are due to the fact that it is in these States where most of those State agencies capable of conducting complete programs of biological control exist. Another contributing factor is, of course, the fact that in these States biological control work has been supported for the longest period of time (more than 70 continuous years).

Major Programs of Biological Control Presently Supported by State Agencies

Major pest targets against which State-initiated biological control efforts are presently being directed include:

(1) California (Berkeley) (professional staff, 10)

- (a) Alfalfa pests (alfalfa weevils, spotted alfalfa aphid, pea aphid)
- (b) navel orangeworm on almond and walnut
- (c) peach twig borer on peach
- (d) codling moth on apple, pear, walnut
- (e) walnut husk fly, walnut aphid, and dusky veined aphid on walnut
- (f) aphids attacking urban street trees (linden, sycamore, birch, oak, elm)
- (g) scales, mealybugs, mites attacking citrus in the Central Valley of California
- (h) mosquitoes
- (i) weeds: yellowstar thistle, Russian knapweed, field bindweed, poison oak

(2) California (Riverside) (professional staff, 15)

- (a) citrus scales and mites
- (b) pink bollworm on cotton
- (c) mosquitoes
- (d) dairy, poultry, feedlot flies
- (e) comstock mealybug
- (f) weeds: Russian thistle, Italian thistle, milk thistle, puncture vine
- (g) vegetable pests: potato tuber moth, cabbageworms, armyworms
- (h) woolly whitefly on citrus

(3) Florida

- (a) Mexican bean beetle on soybean
- (b) citrus whitefly
- (c) citrus snow scale
- (d) caribbean fruit fly
- (e) southern green stinkbug
- (f) sugarcane rootstalk borer weevil
- (g) fire ant
- (h) weeds: Hydrilla spp., strangler vine
- (i) fall armyworm

(4) Hawaii

(a) southern green stinkbug
(b) sugarcane pests
(c) albizzia psyllid
(d) banana skipper
(e) tropical fruit flies
(f) corn, sorghum, and rice pests
(g) spider mites

(5) Virginia

(a) musk thistle
(b) plumeless thistle

There are also several major programs of biological control involving cooperative efforts between State and Federal agencies. These include:

(1) gypsy moth (New England States)

(2) cereal leaf beetle (Great Lakes States)

(3) aphids on sorghum, maize, wheat (Midwestern and Southwestern States)

(4) tussock moth (Far Western States)

And, finally, there should be mentioned the federally funded (through Cooperative State Research Service, U. S. Department of Agriculture) Regional Research Project, W-84, entitled "Conservation and Augmentation of Biological Control Agents through Environmental Manipulation" which includes both personnel and facilities of eight State University agricultural experiment stations.

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